ENERGY SECTOR PROGRESS REPORT

Economic & Technology Advancement Advisory Committee (ETAAC)

5-31-2007

ETAAC Energy Sector Technologies That Will Be Reviewed

1. Carbon Capture and Sequestration
2. Emerging Renewable Technologies
3. Combined Heat and Power / Distributed Generation
4. Advanced Coal Technologies
5. Nuclear Technology
6. Advanced Natural Gas Generation
7. Energy Efficiency
8. Energy Storage
9. Wind
10. Biomass, Landfill and Methane Digester
11. Solar
12. Geothermal
13. Non-Electric Generation Gas Technologies

Progress to Date

1) Energy Sector Meeting, May 10, 2006, Sacramento
   A) Carbon Capture and Sequestration.
      1) Greg H. Rau, UC-Santa Cruz, LLNL

         "The Essential Role of CO_2 Sequestration in Stabilizing Atmospheric CO_2".
      2) Larry Myer, WESTCARB, CEC, LBNL

         "CO_2 Sequestration Options for Californians".
   B) Emerging Renewable Technologies
      1) Hal LaFlash, PG&E

2. Input from CEC and Water Quality Control Board on Status of Bioenergy Working Group

ETAAC Energy Sector: Technology Status Outline

1) Technology Description
   Describe the technology and possible applications.
2) Potential to Reduce Greenhouse Gas
   Estimate (in tons) the potential for removing, offsetting or displacing greenhouse gas emissions.
3) Status of Commercialization
   Is the technology commercially available? If not, what is the status of development/ commercialization? How soon will the technology be commercialized?
4) Barriers to Entry
   What are the barriers to entry?
   a) Technology- Are there significant technological barriers?
   b) Financial-Are there cost, financing, or "pay back" hurdles?
   c) Institutional-Are there market or perception challenges?
   d) Regulatory- Are there legal or regulatory barriers to development?
5) Solutions
   Provide any specific policy or other action which can be taken encouraging the commercialization of the technology.

ETAAC: Template for Technology Summary

Technology	Technology Overview	CO_2 Abatement Potential	LCOE in 2007	$/ton of CO_2 Abated	Status/Timing of Commercialization	Barriers to Entry			
						Technological	Financial	Institutional	Regulatory
Advanced Solar Thermal	-	-	-	-	-	-	-	-	-
Concentrating PV	-	-	-	-	-	-	-	-	-
Advanced Silicon PV	-	-	-	-	-	-	-	-	-
Thin Film PV	-	-	-	-	-	-	-	-	-
Anaerobic Digesters	-	-	-	-	-	-	-	-	-
Landfill Gas	-	-	-	-	-	-	-	-	-
Biomass Gasification	-	-	-	-	-	-	-	-	-
Biomethanation	-	-	-	-	-	-	-	-	-
Biodiesel	-	-	-	-	-	-	-	-	-
Geothermal	-	-	-	-	-	-	-	-	-
Wind	-	-	-	-	-	-	-	-	-
Advanced Wind	-	-	-	-	-	-	-	-	-
Tidal	-	-	-	-	-	-	-	-	-
Wave Power	-	-	-	-	-	-	-	-	-
Fuel Cell w/RE fuel	-	-	-	-	-	-	-	-	-

Schedule

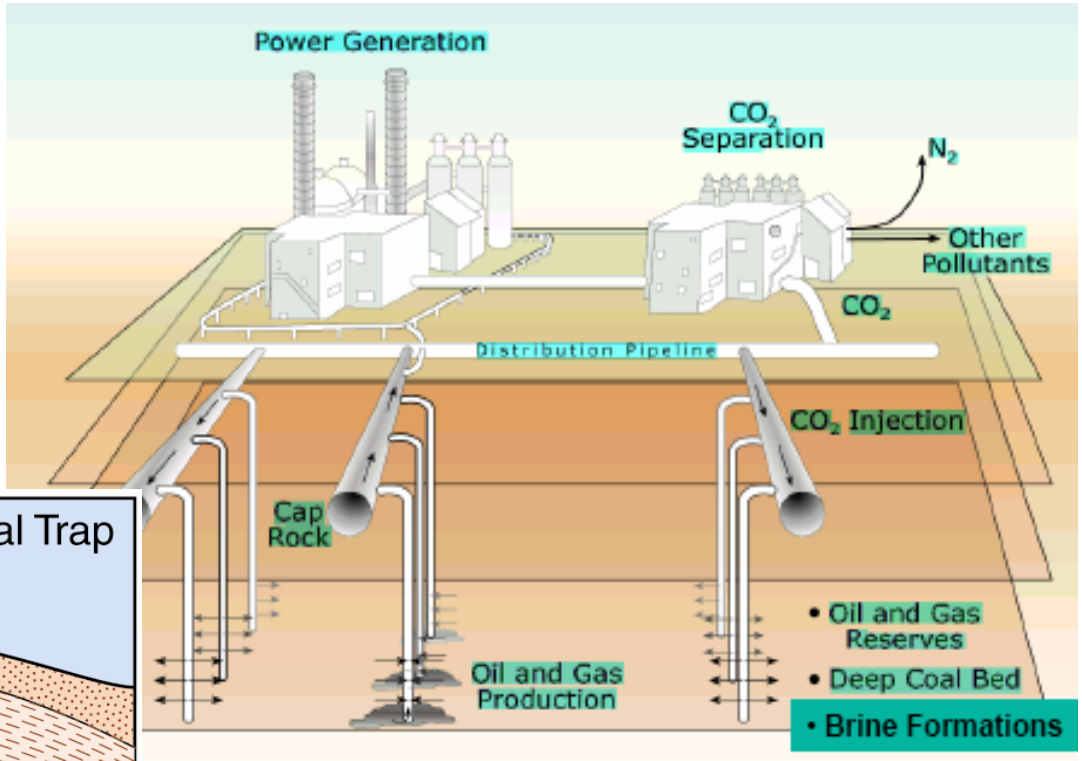
June	**1) Combine Heat and Power**
	2) Distributed Bioenergy
	3) Nuclear
July	**1) Advanced Coal**
	2) Energy Efficiency
	3) Energy Storage
August	**1) Wind**
	2) Solar
	3) Geothermal
September	**1) Biomass, Landfill, Methane Digester**
	2) Non-Electric Gas Technology

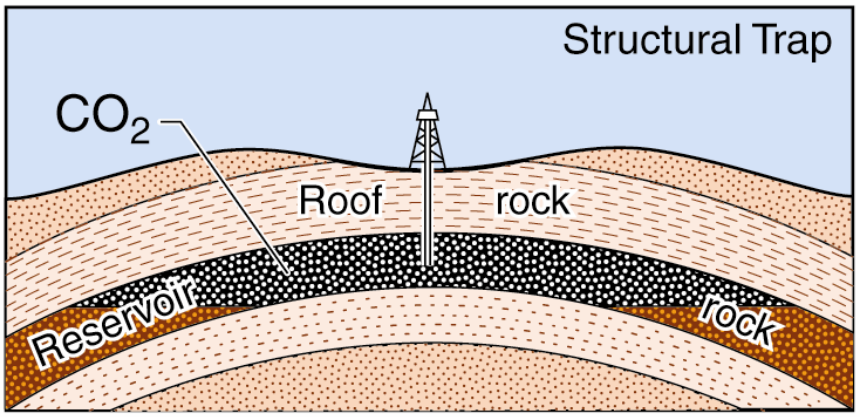
CARBON CAPTURE

AND SEQUESTRATION

Geologic Storage Mechanisms

- Physical, hydrodynamic, trapping
- Dissolution
- Phase trapping
- Mineralization
- Surface adsorption





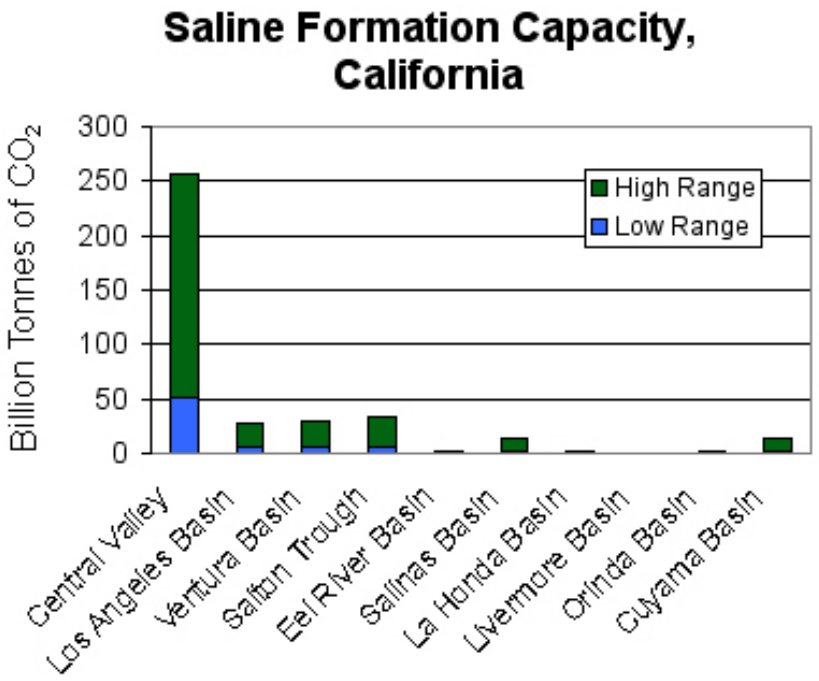
Slide provided by: Provided by West Coast Regional Carbon Sequestration Partnership

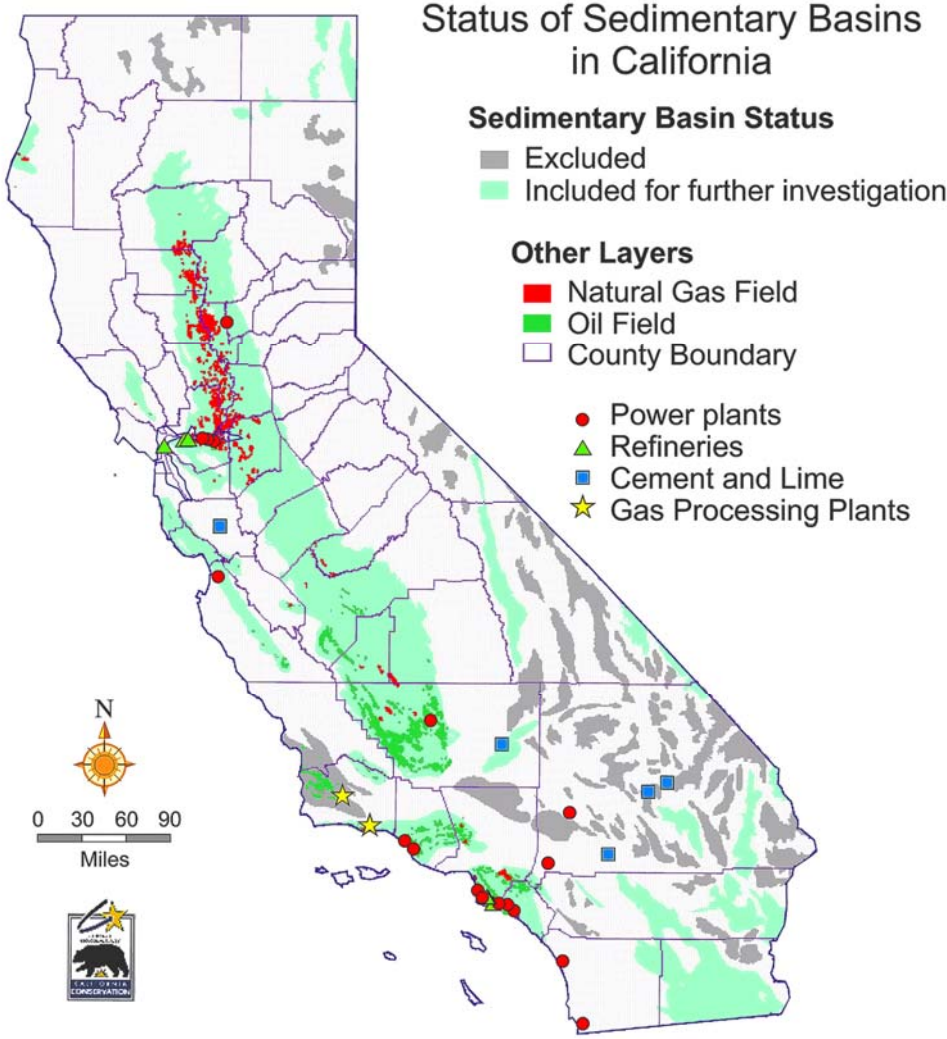
Primary Storage Options

- Oil and gas reservoirs
  - Storage with Enhanced Oil Recovery (EOR), Enhanced Gas Recovery (EGR)
  - Storage only
- Deep, unminable coal beds
  - Storage with Enhanced Coal Bed Methane (ECBM) recovery
- Saline formations
  - Storage only

Slide provided by: Provided by West Coast Regional Carbon Sequestration Partnership

Major Geologic Storage Opportunities in California

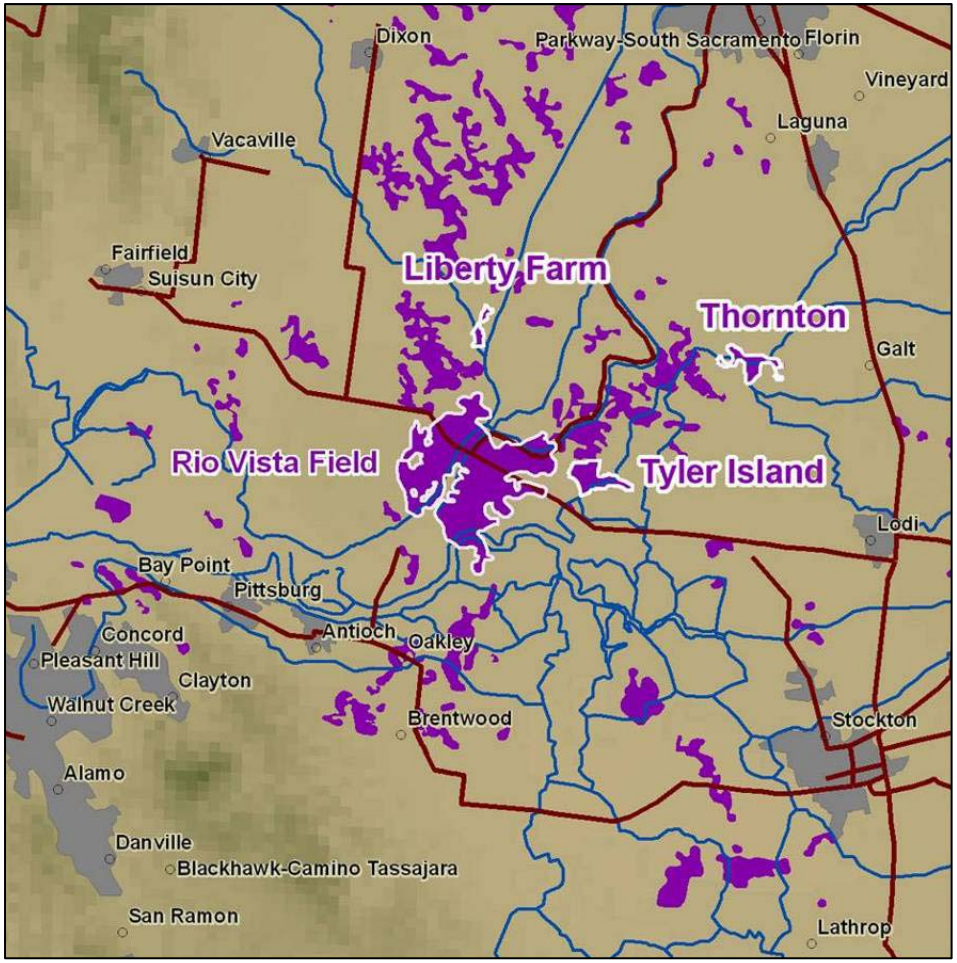




Gas reservoir capacity: 1.7Gt
Oil reservoir capacity: 3.6Gt

Slide provided by: Provided by West Coast Regional Carbon Sequestration Partnership

Rosetta Resources CO_2 Storage Pilot

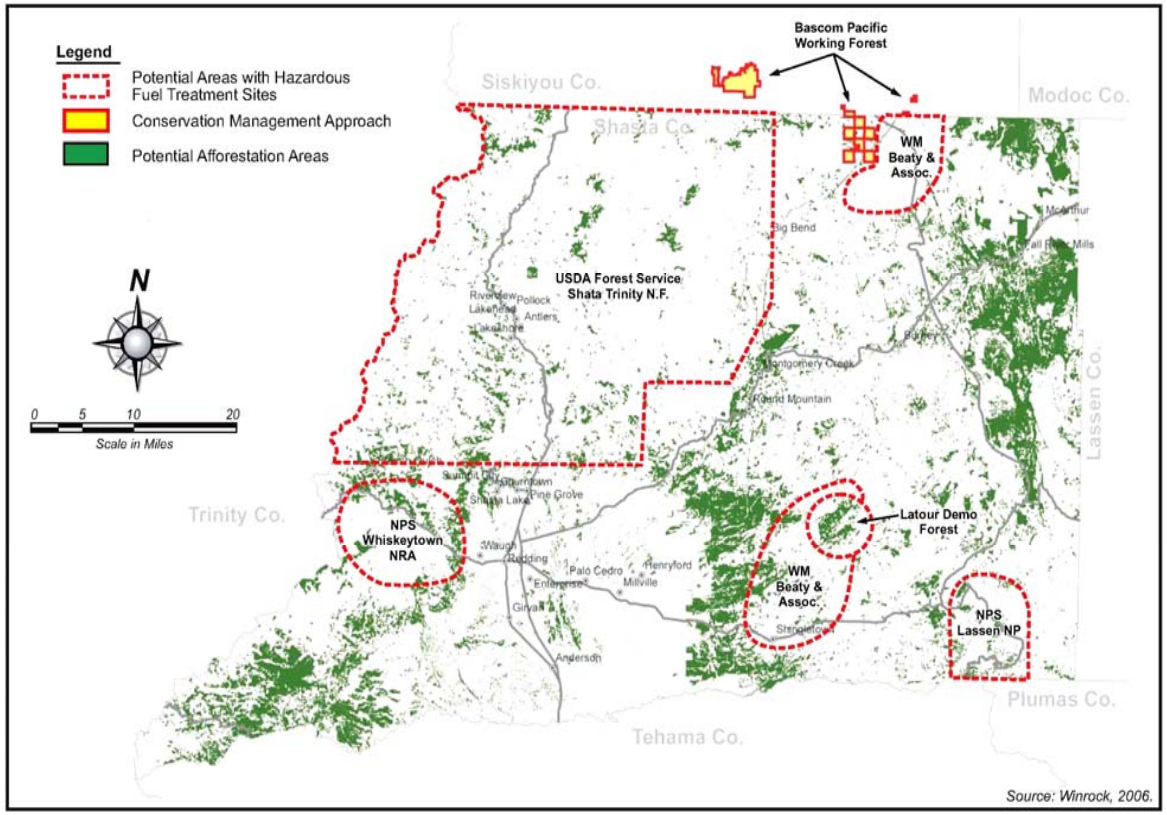


- Lead industrial partner: Rosetta Resources
- Validate sequestration potential of California Central Valley sediments
- Test CO_2 Storage Enhanced Gas Recovery
- Inject about 2000 tons at about 3400ft depth
- Focus on monitoring

Slide provided by: Provided by West Coast Regional Carbon Sequestration Partnership

Shasta County Terrestrial Pilot

- Validation of forest growth type for rangelands
- Develop and test fuel management activities; baselines and measurement and monitoring
- Validate emissions reductions from conservation and sustainable forest management practices



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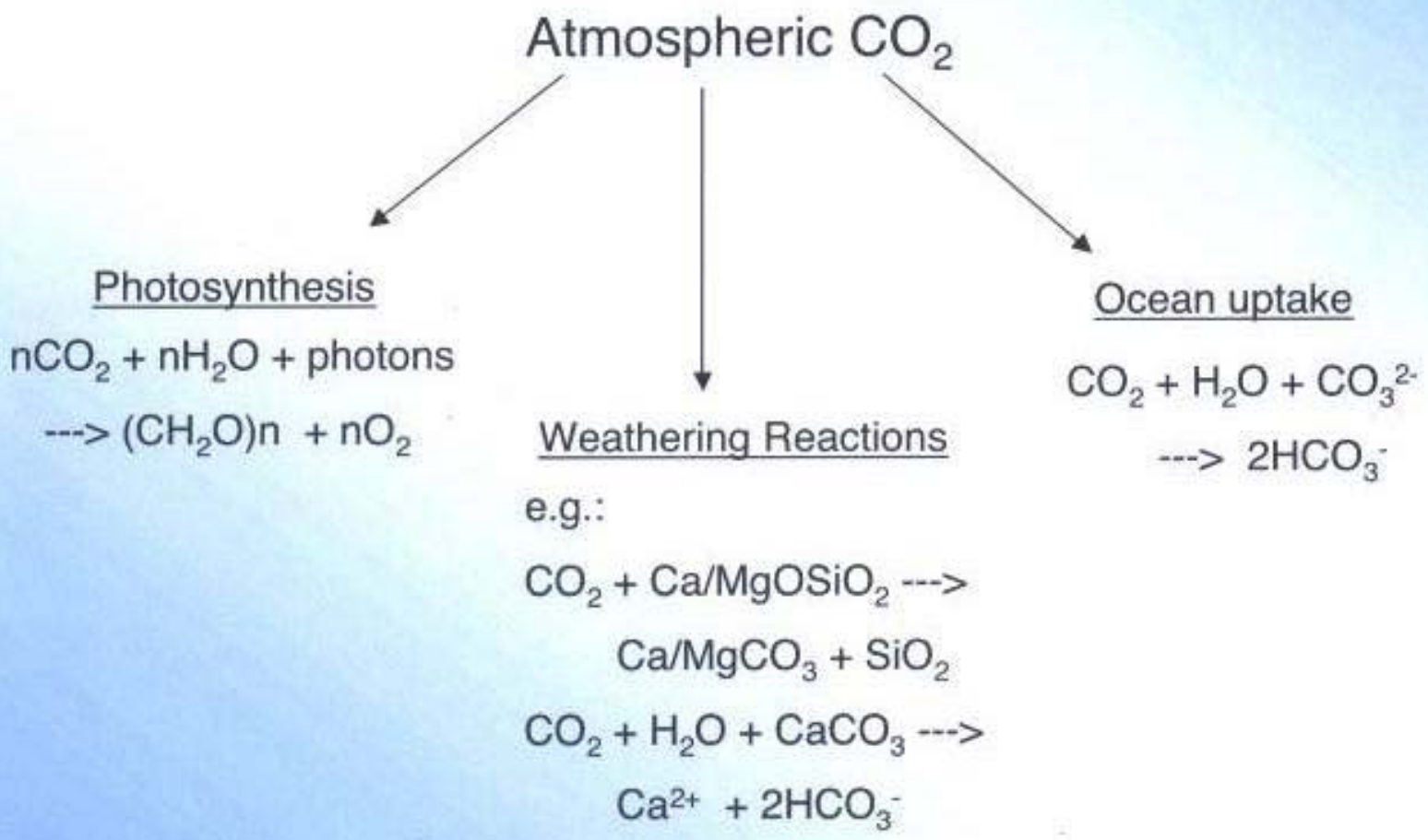
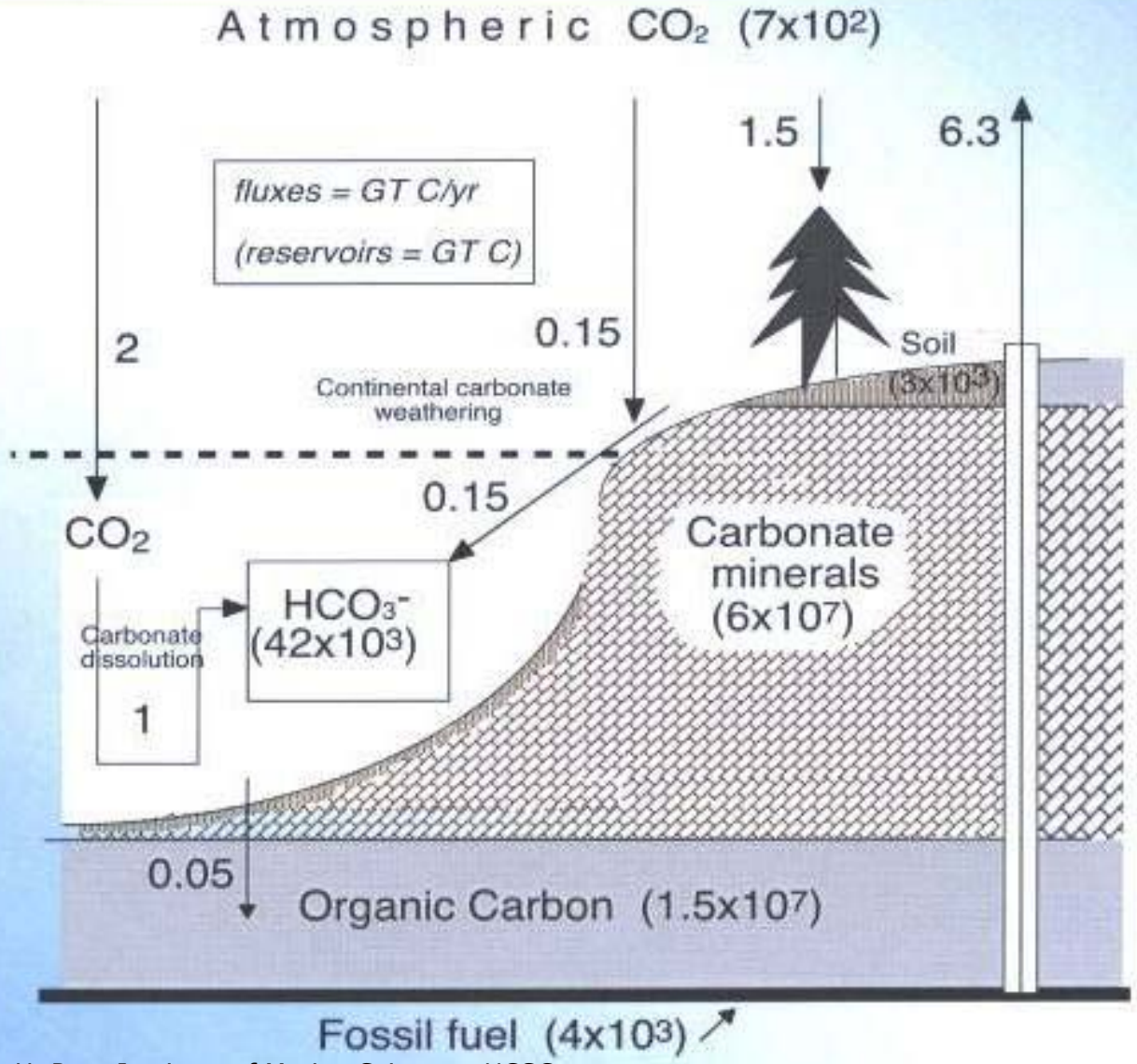
Nature's Chemical CO_2 Capture and Storage:

Nature's own mechanisms:



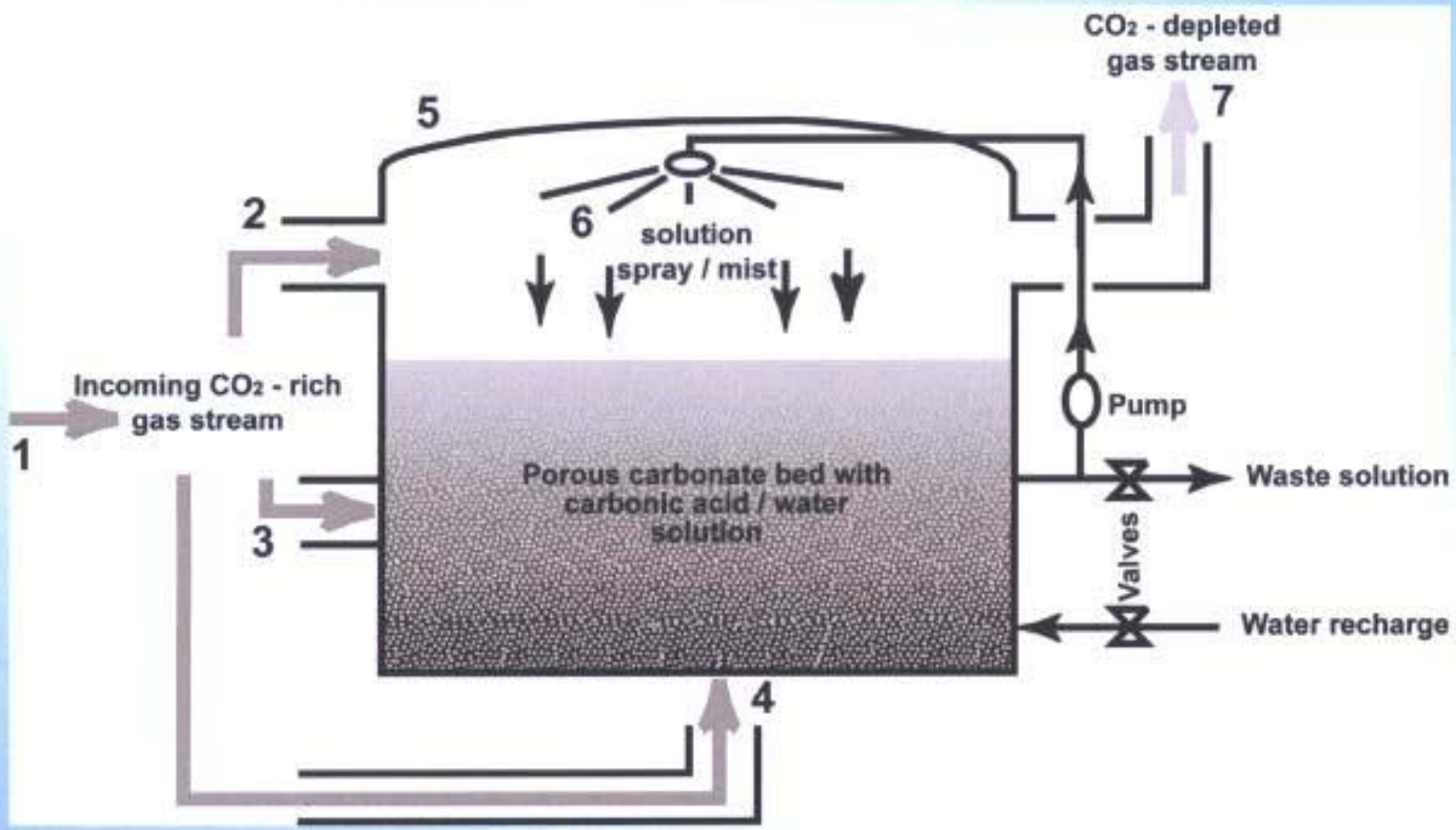
Provided by Greg H. Rau, Institute of Marine Sciences, UCSC

Carbonate Weathering in the Global Carbon Cycle:



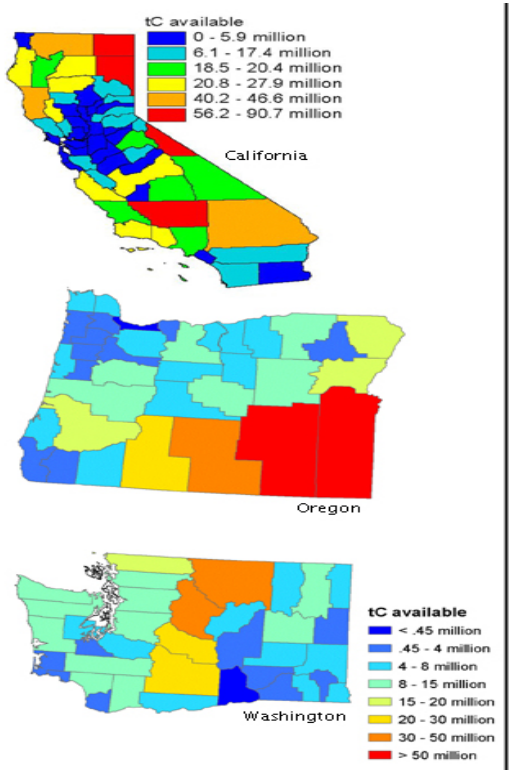
Provided by Greg H. Rau, Institute of Marine Sciences, UCSC

Accelerated Weathering of Limestone (AWL) Reactor:

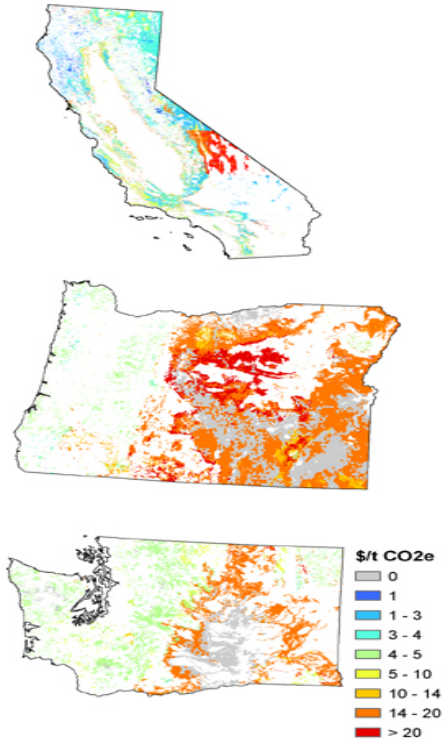


(Rau and Caldeira, 1999)

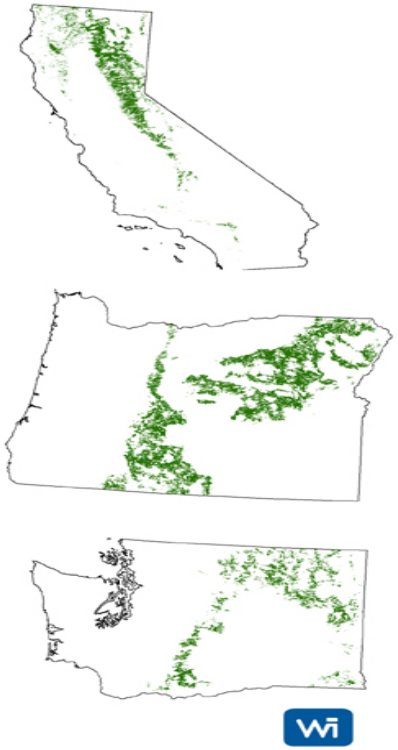
Afforestation and Fuel Management are Major Terrestrial Opportunities in California



40 year sequestration potential



40 year marginal costs



Lands suitable for fuel removal

Slide provided by: Provided by West Coast Regional Carbon Sequestration Partnership

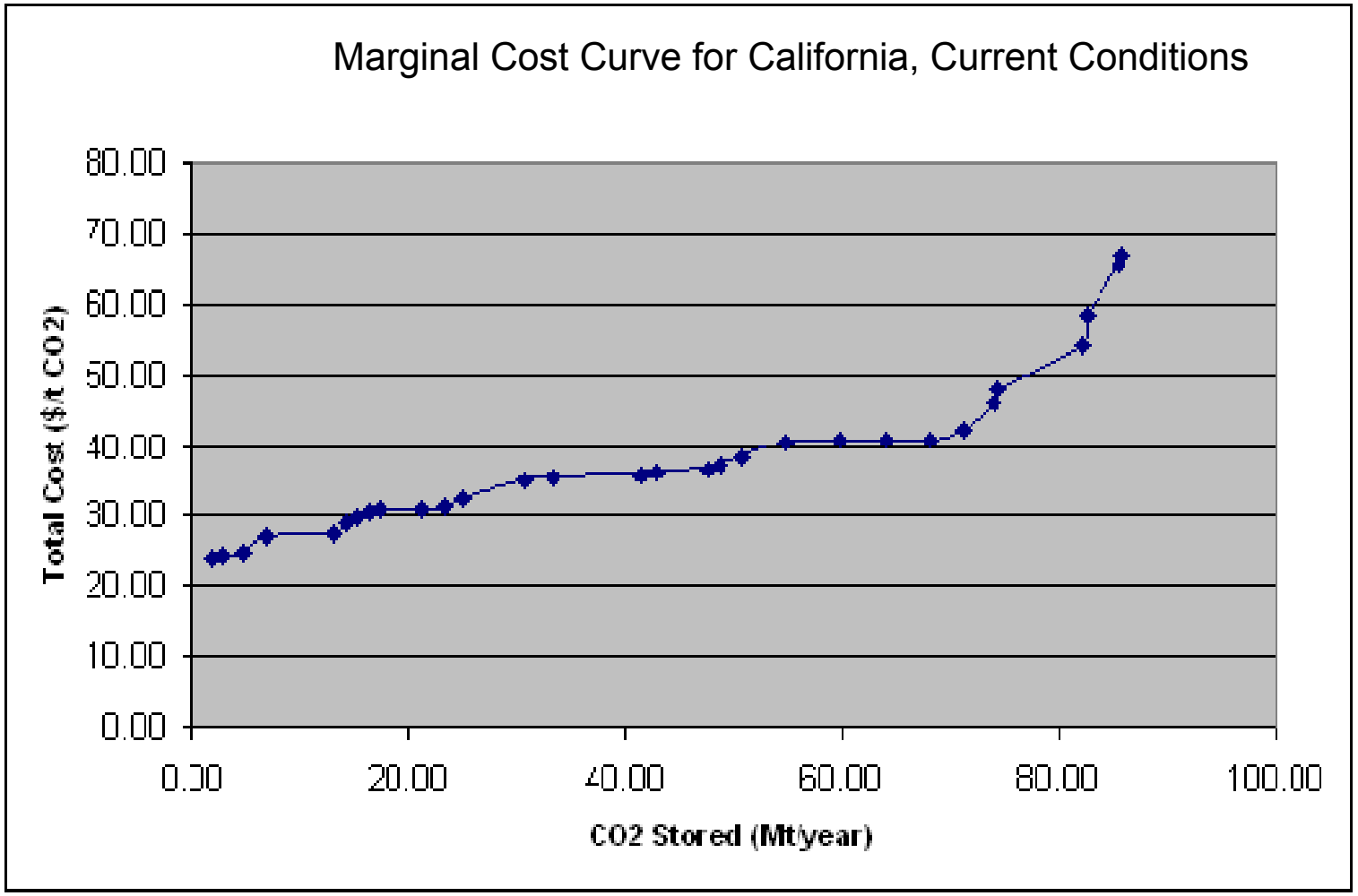
Other Sequestration Alternatives

Bottom Line: Use the chemical reactivity of CO_2 for CO_2 mitigation.

Potential Technologies

- **Accelerated weathering of limestone reactor**
- **Combined CO_2 and kiln dust mitigation**
- **CO_2 sequestration using H_2O co-produced with oil**
- **Iron / CO_2 fuel cells**

Carbon Sequestration



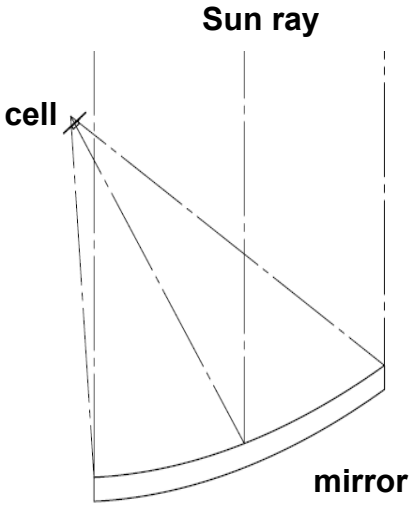
Source: H. Herzog, MIT via West Coast Regional Carbon Sequestration Partnership

EMERGING

RENEWABLES

(EXAMPLES)

Concentrating Photovoltaic



Operation: Light reflects off tracking mirrors to fixed overhead panel. The concentrated light is converted to electricity by photovoltaic cells. ~200watts/unit

Key Advantage: Modular design and direct solar-to-electric conversion. No working fluids.

Key Challenge: Getting the power cost down via efficiency improvement, technology development and manufacturing to scale.

Concentrating Thermal Trough

Compact Linear Fresnel Reflector (CLFR)

Operation: Elliptical Mirror concentrates sunlight to heat oil traveling through tube. Hot oil used to generate steam and operate a turbine connected to generator.

Key Advantage: Technology is proven and has large-scale operating history. Potential to dispatch with natural gas.

Key Challenge: Core Technology is 20+ years old and has limited improvement potential. Design is very capital intensive. CLFR less expensive.

Concentrating Thermal Tower

Operation: Mirrors focus sunlight on a central tower, where water is heated to generate steam. Steam is used to spin a turbine connected to generator.

Key Advantage: Higher efficiency, simpler design, lower installation cost. Dispatchable with gas-fired boiler.

Key Challenge: No long-term operating history. Original version 20 years ago, new versions under development or construction

Technology Comparison

	Trough	Dish	Tower	CPV
Technology Maturity	High – in production	Medium – working prototypes	Low – R&D needed	Low – still in R&D
Working Fluid	Synthetic Oil, water for steam	Hydrogen Gas	Water/steam	None
Energy Conversion	Steam Turbine	Reciprocating Engine	Steam Turbine	Direct solar to electric conversion
Dispatchable	Yes, if designed to (currently solar-only)	No	Yes	No
Time to Market	2010+	2011+	2010+	2007+
Technology Risk	Low, working in field	Medium, risk on scaling up	High, still in R&D	High, still in R&D
Price per MWh	~$100-120/MWh	~$80-90/MWh	~ 100-120/MWh	~$200/MWh+

Overview – Wave Technologies

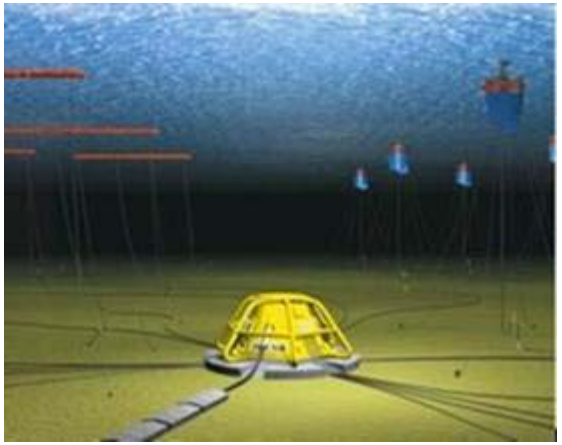
Ocean Power Delivery Pelamis

AquaEnergy AquaBuOY

Ocean Power Technology PowerBuoy ™

OPD Pelamis Wave Plant ('Farm')

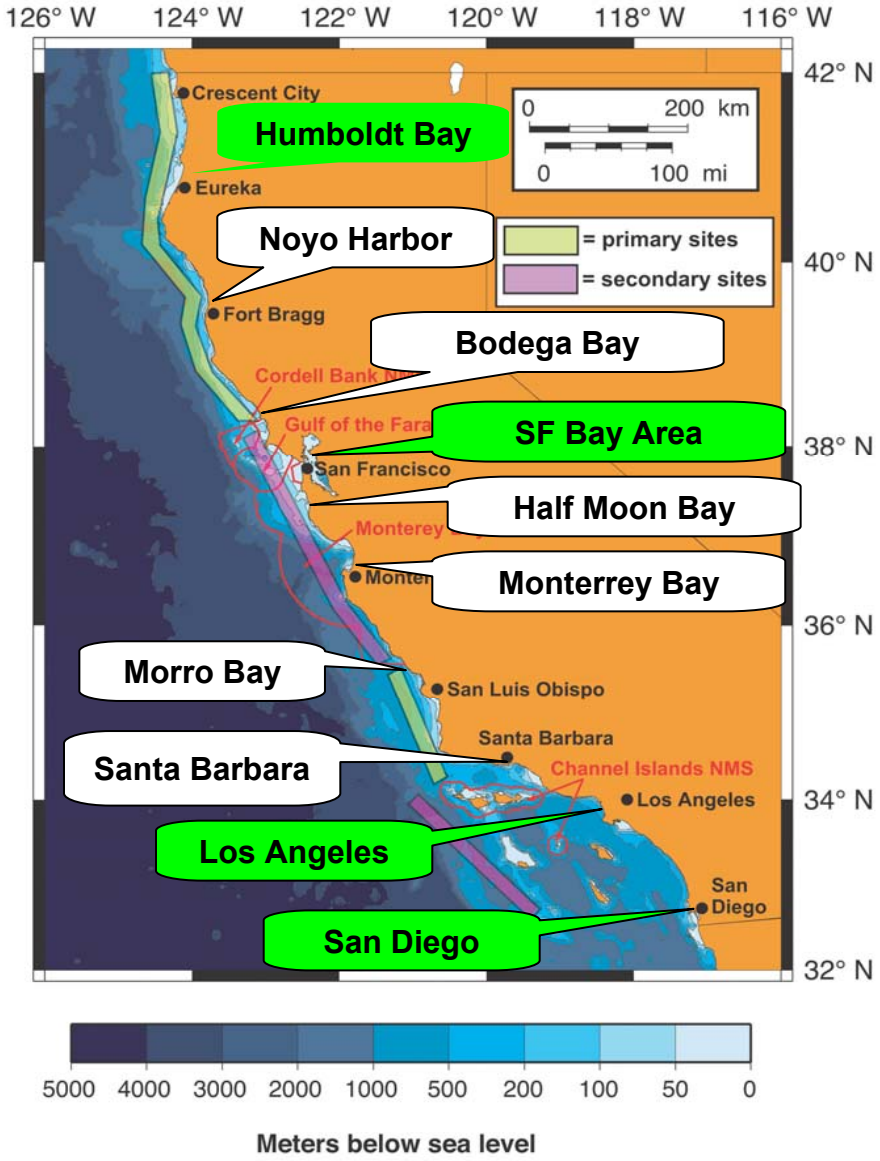
UK Wave Hub



Wavebob

Devices and technologies pictured for illustration / discussion only
Does not reflect or imply any PG&E preference

Potential California Wave Power Generation

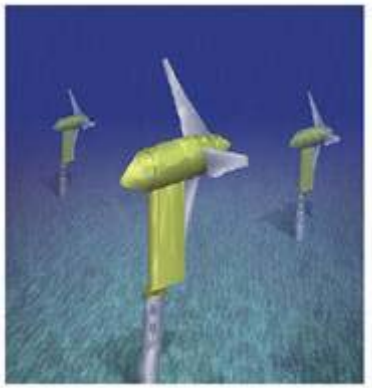


- **Selection criteria for initial sites**
  - Grid interconnection
  - Wave resource
  - Port infrastructure (deepwater ports shown in green)
  - Local support
- **PG&E filed two FERC preliminary permit applications (40MW each)**
  - Humboldt County (Eureka)
  - Mendocino County (Fort Bragg)
- **Wave power plant**
  - Multiple wave energy conversion devices arranged in an array
  - Leading devices float on surface of water
  - 0.5-10 miles offshore
  - Connected to land via subsea cable

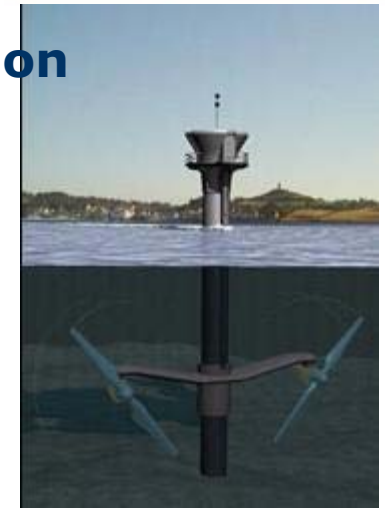
Tidal Power Turbines

Verdant Power Turbine – East River Project

Installation Illustration



MCT Seaflow- SeaGen Turbines – UK Installation



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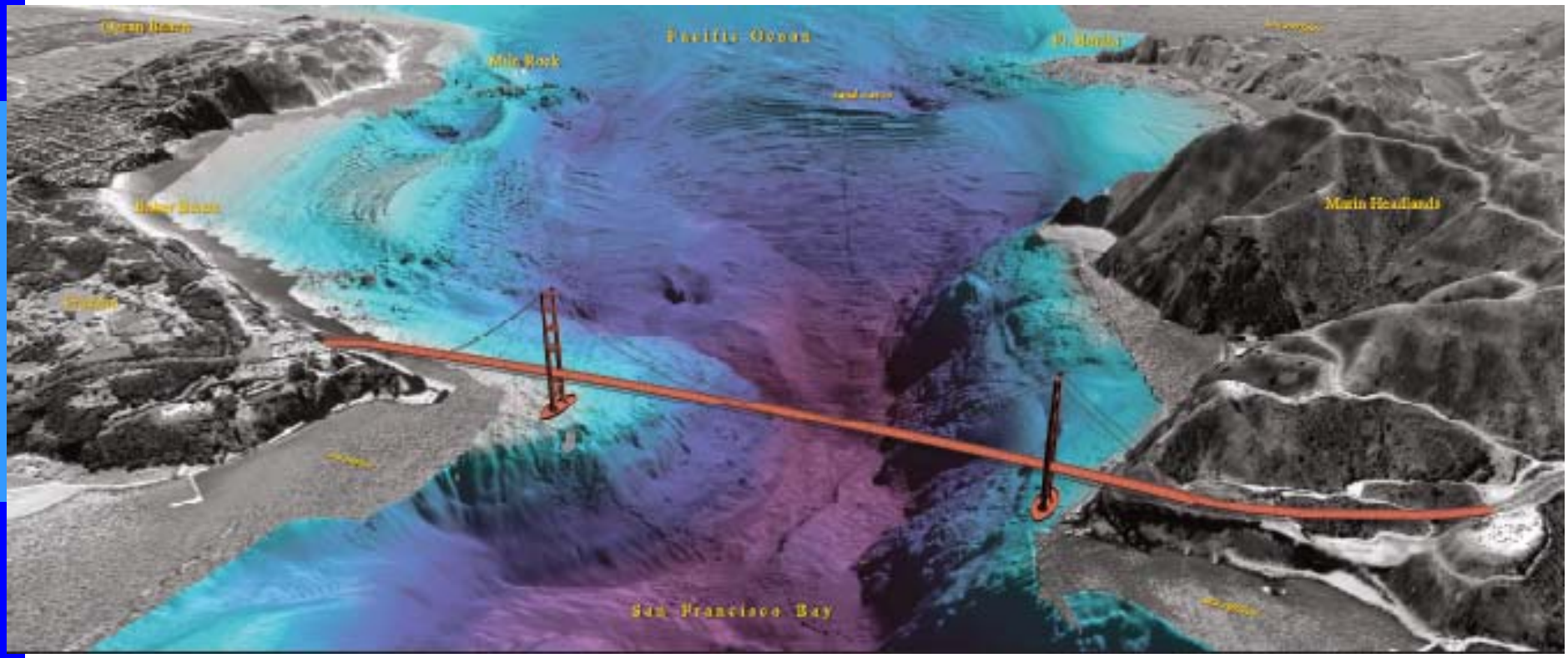
USGS Bathymetry Map of SF Bay

Ocean



maximum depth = 377 feet

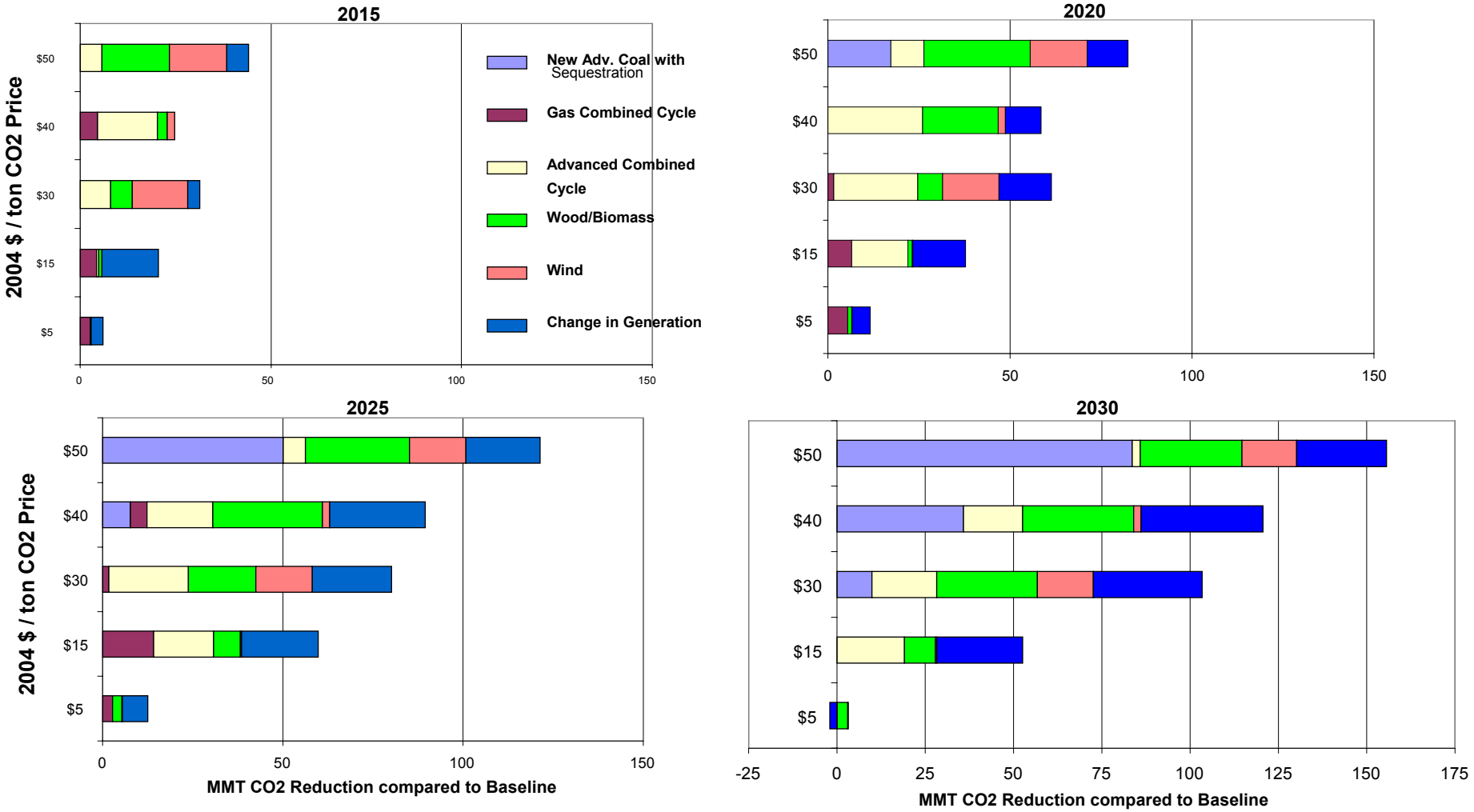
Bay

Source: http://pubs.usgs.gov/sim/2006/2917/sim2917.pdf

Conclusions

- There are a significant number of technologies which may produce energy that displaces carbon dioxide emissions or captures and sequesters carbon.
- Further investigation is warranted on carbon capture and sequestration.
- Carbon capture and sequestration will raise regulatory and liability issues.
- Emerging renewable technologies are under RD&D, utilizing a number of different renewable resources.
- Long-term commercialization of emerging renewable technologies is highly dependent on technological advances, cost reductions, and addressing environmental issues.

Sample CO_2 Abatement Supply Curves for California



Source: Nicholas Institute analysis using the NEMS model, February 2007